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Weather and environmental effects on dismounted soldiers can substantially impair mission performance and, in the extreme, may result in severe or life threatening thermal injuries. An automated real-time capability to assess these soldier system risks in the temporal and spatial domain of dismounted infantry battlespace scenarios is synergistic with larger efforts to improve the overall effectiveness of dismounted warfighters. We have completed initial integration of a suite of human thermal strain prediction models with automated real-time weather and terrain information resources. Current models predict scenario-dependent exposure limits in hot or cold environments and during cold water immersion. In June 1996 a test bed system was installed at the U.S. Army Ranger training facilities at Camp Rudder, Eglin Air Force Base, Florida. The MERCURY-Ranger Test Bed system uses the existing network resources and automated weather data acquisition infrastructure at Eglin to obtain required predictive model inputs such as air temperature, humidity, wind speed, solar radiation and, for the cold immersion model, water temperature and depth. Using standard Internet connections between MERCURY and Eglin's Range Automated Weather Stations (RAWS) base station computer, weather data from seven to ten RAWS stations are automatically ingested at hourly intervals. These geo-located weather data sets are then interpolated in the context of Digital Topographic Elevation Data (DTED) to provide gridded weather information at 1 km spatial resolution across a 100 by 100 kilometer Eglin area window. Individual weather parameters or predictive model outputs are then displayed over a DTED greyscale image as simple color-coded overlay products. The test bed is used to validate methods needed to extend this capability to operational settings.

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AUTOMATED THERMAL INJURY RISK ASSESSMENT IN THE DISMOUNTED INFANTRY BATTLESPACE

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ABSTRACT

Weather and environmental effects on dismounted soldiers can substantially impair mission performance and, in the extreme, may result in severe or life threatening thermal injuries. An automated real-time capability to assess these soldier system risks in the temporal and spatial domain of dismounted infantry battlespace scenarios is synergistic with larger efforts to improve the overall effectiveness of dismounted warfighters. We have completed initial integration of a suite of human thermal strain prediction models with automated real-time weather and terrain information resources. Current models predict scenario-dependent exposure limits in hot or cold environments and during cold water immersion. In June 1996 a test bed system was installed at the U.S. Army Ranger training facilities at Camp Rudder, Eglin Air Force Base, Florida. The MERCURY-Ranger Test Bed system uses the existing network resources and automated weather data acquisition infrastructure at Eglin to obtain required predictive model inputs such as air temperature, humidity, wind speed, solar radiation and, for the cold immersion model, water temperature and depth. Using standard Internet connections between MERCURY and Eglin's Range Automated Weather Stations (RAWS) base station computer, weather data from seven to ten RAWS stations are automatically ingested at hourly intervals. These geo-located weather data sets are then interpolated in the context of Digital Topographic Elevation Data (DTED) to provide gridded weather information at 1 km spatial resolution across a 100 by 100 kilometer Eglin area window. Individual weather parameters or predictive model outputs are then displayed over a DTED greyscale image as simple color-coded overlay products. The test bed is used to validate methods needed to extend this capability to operational settings.

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1. INTRODUCTION

1.1 Dismounted Infantry Battlespace. One of the most austere and demanding military environments is that experienced by the dismounted infantry soldier during sustained or continuous combat operations. The soldier, and the equipment he carries to establish a tactical advantage in survivability and lethality, must function in a temporally and spatially dynamic natural environment. Local weather conditions and the physiological demands of movement over terrain, load carriage, and chemical protective clothing can interact to produce a significant impact on both the health and performance of the soldier system (Matthew and Santee, 1991). Although considerable meteorological resources are focused on aviation operations and atmospheric conditions above tree top level, it is the very lowest part of the atmosphere that affects humans on the ground. The vertical dimension for the volume space in which the dismounted soldier operates is the lowest two meters of the atmosphere, down to and including the surface terrain. In field training or operational settings, the horizontal dimensions are typically on the order of tens of kilometers across the terrain. The potential for physiologically significant spatial and temporal differences in environmental parameters within this "human-scale" battlespace is substantial (Santee et al., 1994). In spite of the inherent complexity of lower boundary layer meteorology, a growing recognition of the tremendous influence of surface level atmospheric effects on battlefield systems has driven requirements for improved tactical weather information resources. Current efforts to exploit, validate, and integrate those technologies needed to develop near real-time soldier system oriented decision aids are necessary and synergistic with the wider Army thrust to manage battlefield weather effects on the total warfighting system.

1.2 Assessing Thermal Injury Risks. The ability to identify and quantify thermal injury risk to warfighters in real-time training or operational settings, without direct physiological measurements, is an important baseline capability for command and control . Thermal strain prediction models, mathematical representations of what we know about human responses to the environment, provide a way to integrate human and mission-related factors with weather data to estimate soldier-system effects. The practical application of these models is critically dependent upon the availability of weather data across the domain. Evolving battlefield computer and communications resources provide the essential infrastructure needed to automatically ingest weather information and could run appropriate soldier system-oriented predictive models.

1.3 The MERCURY System. Originally developed by the Army Research Laboratory's Battlefield Environment Directorate as an integrated software system for acquiring, analyzing, and extrapolating meteorological data in real time, MERCURY provides an automated capability to spread data from a limited number of weather stations across a region roughly 100 by 100 km at up to km spatial resolution (Fields et al., 1992). The resulting gridded weather data, as well as informational products derived from that data, can be visualized in MERCURY as digital terrain overlay images. A logical extension of these capabilities is real time overlay products focused on thermal injury risk assessments for dismounted infantry scenarios. The fusion of MERCURY's intermediate process weather products with physiological models provides the spatial and temporal context relevant to warfighters in the dismounted infantry battlespace. In

1993 we began an effort to develop software interfaces that would enable thermal strain prediction models to exploit MERCURY's gridded weather data as input fields in a highly automated, real time computing and display environment. The USARIEM Heat Strain Model (Pandolf et al., 1986; Gonzalez and Stroschein, 1991) was the first thermal strain prediction model to be integrated with MERCURY. Science Applications International Corporation (SAIC) completed the initial Prototype MERCURY/Heat Strain software in February 1994 (McNally et al., 1994; Matthew et al., 1994). In October 1994 we obtained approval to incorporate a Cold Survival Time model developed by the Defence and Civil Institute of Environmental Medicine (DCIEM), Ontario, Canada (Tikuisis and Frim, 1994; Tikuisis, 1995).

1.4 The MERCURY-Ranger Test Bed. In February 1995, four hypothermia deaths occurred among U.S. Army Ranger students during swamp training exercises along the Yellow River, Eglin Air Force Base, Florida. This incident sparked a critical reevaluation of current procedures and resources for thermal injury risk assessment in general and hypothermia in particular. Following a briefing of MERCURY's current and planned capabilities to the Ranger leadership in May 1995, it was determined that the installation of a test bed MERCURY system at Camp Rudder would benefit the Ranger training operations there (McWilliams, 1996). Initial installation was completed in June 1996 and DCIEM's prototype cold immersion model was added in October 1996.

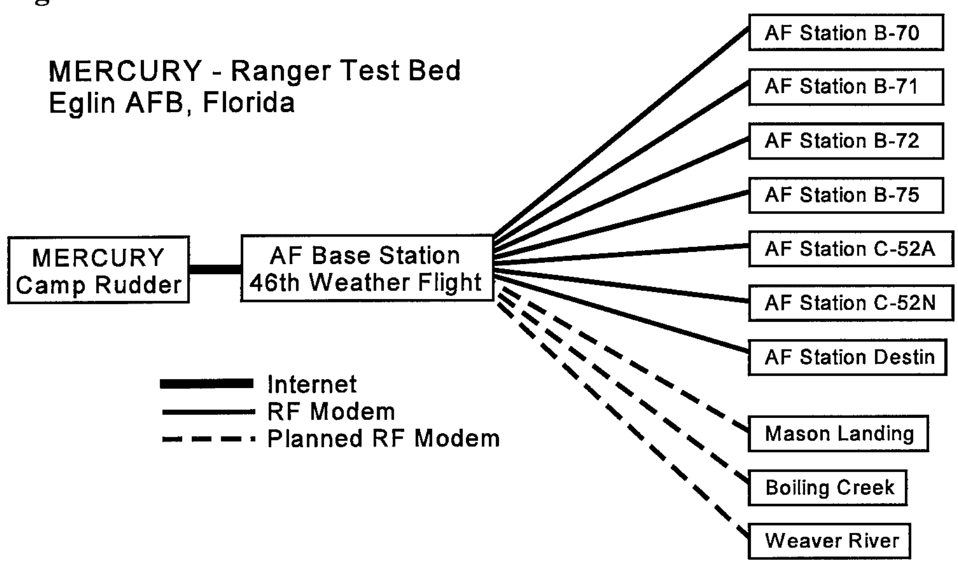
2. OBJECTIVES AND SCOPE

Our primary objective is to briefly describe the MERCURY- Ranger Test Bed system currently located at Camp James E. Rudder, Eglin AFB, Florida. Scope is limited to functional descriptions of the local infrastructure support that enables the continuous weather data input stream to MERCURY, the suite of physiologically based thermal strain prediction models that have now been linked within it, and the user level input and output display facilities. The origin and development of MERCURY's weather spreading algorithms/heuristics as well as estimates of their performance accuracy have been described previously (Fields et al., 1992) and will not be addressed in this paper.

3. SYSTEM DESCRIPTION

3.1 Overview. The Ranger Test Bed consists of three essential components: The fixed site weather stations deployed across Eglin, the communications systems that connect the stations with MERCURY , and finally, the Unix computer running MERCURY that controls the data flow, accepts the user input, processes the data and displays the output product. An overall schematic of the current system is shown at Figure 1.

Figure 1. Schematic overview.



It should be noted that the link between the Air Force central weather station computer at Eglin and MERCURY at Camp Rudder is an Internet link using standard Transmission Control Protocol/Internet Protocol (TCP/IP). This means that MERCURY can be run remotely, in real time, for any region in the world that has Internet accessible hourly local weather station data.

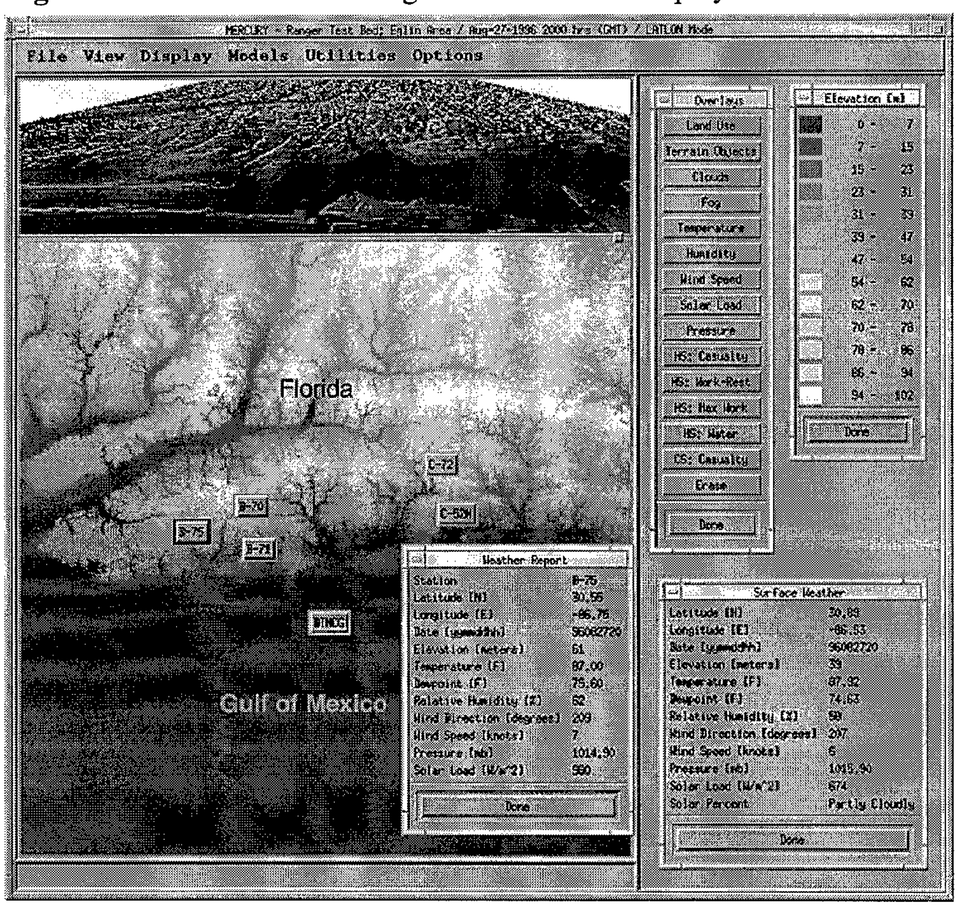
3.2 Weather Stations. Seven automated weather stations located across the Eglin area are controlled and maintained by the U. S. Air Force. This system, known as the Range Automated Weather Stations (RAWS) is critical supporting infrastructure for the MERCURY implementation at Camp Rudder. The weather stations automatically measure and record air temperature, humidity, wind speed, wind direction, solar radiation, barometric pressure, rainfall and other parameters that relate to forest fire hazards. Three additional weather stations, purchased by the Rangers and located along the Weaver and Yellow Rivers, measure water temperature and depth as well as the standard RAWS parameters.

3.3 Weather Data Communications Links to MERCURY. At hourly intervals, date and time stamped weather data, along with each station's identification code, are transmitted by radio frequency modem to a central computer, the RAWS base station, located at the U.S. Air Force 46th Weather Flight offices at Eglin. In early 1997 the three stations along the Yellow and Weaver rivers, currently accessible by cell phone modem only, will be connected to the RAWS base station by radio frequency modem. Because the weather data files on this computer are accessible using TCP/IP and the network File Transfer Protocol (FTP), national infrastructure communications resources can be exploited to complete the link between the weather station sensor readings and MERCURY.

3.4 The MERCURY Computer System. The MERCURY computer at Camp Rudder runs under a Unix operating system. A Sun SPARCstation 5, running Sun Solaris 2.4, provides all needed Internet facilities and the Openwindows windowing environment. MERCURY currently needs a minimum of 48 MBytes RAM and 150 MBytes of free disk space to run. The test bed computer has 96 MBytes of RAM, 4 GBytes of total disk space, a 20 inch color monitor and is linked to the Eglin computer network via ethernet. Every hour the computer automatically connects to the RAWS base station, downloads the latest weather data files via FTP, and, using a specialized parsing procedure, converts the weather data files to the MERCURY format. A Hewlett Packard Color LaserJet printer provides hard copy prints of user selected output images.

3.5 Terrain Data and Field of View. The test bed field of view at Eglin is 1 arc degree of latitude and longitude: from 30° to 31° North Latitude and from 86° to 87° West Longitude. Using those coordinates, Defense Mapping Agency's Level 1 Digital Topographic Elevation Data (DTED) data were extracted from our CDROM library and referenced to the Clark 1866 spheroid to allow geolocation in either latitude/longitude or Universal Transverse Mercator (UTM) coordinate space. The DTED file, in greyscale representation, provides the background image for the overlay products on the MERCURY screen. This region encompasses key sections of the Yellow and Weaver Rivers, where Ranger training is conducted, as well as most of Choctawhatchee Bay and a section of the Gulf coast, East and West of Fort Walton Beach, Florida. A black and white image of a MERCURY display screen is shown at Figure 2.

Figure 2. Black and white image of MERCURY display screen.



3.6 Thermal Strain Models. The thermal strain prediction models currently integrated with MERCURY consist of a heat strain model, a cold survival time model, and a prototype partial immersion hypothermia model. It should be noted that the cold survival time model software module, though not relevant to risk management at Camp Rudder, resides as a potential application for search and rescue operations in other locations.

3.7 Weather Data for the Models. Each of the reporting weather stations is represented by an icon on the MERCURY display window. Data from individual stations may be reviewed by point and click using the computer mouse. The hourly MERCURY-processed weather data used for input to the test bed heat strain and cold survival time model implementations have a spatial resolution of approximately 2.5 kilometers. The Eglin field of view thus represents a 40 by 40 array of 1600 cells, each cell in effect containing an air temperature, humidity, wind speed, and solar radiation value for input to the selected model. The data sets for the partial immersion model consist exclusively of water and ambient atmosphere parameters actually measured by the three stations along the river. The immersion model input and output thus reflects conditions at the three station locations along the river, a "discrete point" rather than "area" representation.

3.8 User Input Requirements. The test bed thermal models share certain common requirements, the most important of which, from a user perspective, is the need for information about the average warfighter being modeled. Although the weather data input stream is automated, the thermal strain models that run within MERCURY require user input of soldier characteristics, clothing type, and the level of physical effort required by the military mission. These inputs, crucial to any realistic determination of risk level by the models, are selected by an intuitive "point and click" graphical interface using the system mouse. Until field validation and sensitivity studies are completed it is not possible to make rational decisions on appropriate default values to streamline the user input process. It is expected that the test bed itself will be a prime resource in those studies.

3.8.1 Heat Strain Inputs. The heat strain model currently requires user input/selection of body height and weight, hydration status (5 categories), acclimatization (days of prior heat exposure), estimated work load (4 categories), and clothing type (5 categories).

3.8.2 Cold Survival Time Inputs. The cold survival time model requires user input/selection of body height and weight, percent body fat, and clothing insulation. This model assumes minimal physical activity.

3.8.3 Cold Water Partial Immersion Inputs. The partial immersion model currently requires user input/selection of body height and weight, percent body fat, age, clothing insulation, non-immersed clothing wetness, walking speed, load carried, and terrain type (4 categories).

3.9 Output from the Models. The common thermal strain model output format in the MERCURY environment is based on a classification of predicted results into three color coded categories: green for low risk, amber for moderate risk, and red for high risk. For the heat strain and cold survival time models, the spatial resolution of the color coded terrain overlay image is currently about 2.5 kilometers, and each output parameter image represents model results from

1600 individual weather data cells within the MERCURY field of view. The output from the cold water partial immersion model is a point estimate for each river station location.

3.9.1 Heat Strain Output. The heat strain model outputs consist of user selectable color coded overlays for casualty risk, optimal work/rest cycle limits, maximum safe work time, and hourly drinking water needs.

3.9.2 Cold Survival Time Output. The cold survival time model output consists of a color coded overlay of time in hours until a body temperature of 30 °C would be reached.

3.9.3 Cold Water Partial Immersion Output. The partial immersion model output is based on the time required to reach a body core temperature of 35.5 °C and the user specified estimate of mission duration. If the time to 35.5 °C is substantially longer than the mission time, the station icon is shown in green. If the time to 35.5 °C is less than the expected mission duration, the station icon is shown in red. Marginal times are shown in amber. By clicking the mouse on the station icon, a text panel showing the predicted values may be viewed.

4. FUTURE EFFORTS

4.1 Validation Studies. Field research studies using soldier volunteers in tactically realistic settings are a critical part of the forward evolution of the MERCURY's thermal stress modeling capabilities. USARIEM will conduct human use approved protocols with Ranger volunteers in 1997 to build the physiological database needed to improve and validate test bed model implementations, and ultimately transition their functionality to operational users.

4.2 Additional Site Implementations. The establishment of additional real-time test beds in other locations will provide an important opportunity to test and evaluate the predicted physiological responses of dismounted soldiers in a variety of terrain types and mission scenarios. USARIEM and ARL will assist the Dismounted Infantry Battlespace Battle Lab with a MERCURY installation at Fort Benning, Georgia in 1997.

4.3 Real Time Physiological Monitoring. The test bed's network and computing resources could also be exploited in real time to process physiological sensor data and display individual warfighter status. In future command and control instantiations, fusion of real time physiological data with predictive models would allow automated input and initialization of individual soldier modeling runs to identify soldiers at risk, well in advance of actual injury.

4.4 Weather Forecast. MERCURY currently relies on hourly weather data to provide products which are essentially a "nowcast." The integration of a high resolution mesoscale weather forecast model with MERCURY's thermal strain models would allow site-specific thermal injury risk predictions out to 24 hours. The Battlescale Forecast Model (BFM), currently under development by ARL's Battlefield Environment Directorate, is an ideal mesoscale model to provide the required gridded weather data.

5. CONCLUSION

The MERCURY-Ranger Test Bed represents an essential first step in defining the technical requirements for operational systems that could provide highly automated, spatially and temporally accurate representations of thermal injury risks in the dismounted infantry battlespace.

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